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Numerical modeling of the plasma response to a local cooling

Mikhail Z. Tokar and Mikhail Koltunov

Institut für Energie- und Klimaforschung – Plasmaphysik, Forschungszentrum Jülich GmbH, Association EURATOM-FZJ, Trilateral Euregio Cluster, D-52425 Jülich, Germany

Outline

→ Impurity injection in fusion devices

→ Mechanisms for cooling of plasma components by impurity

→ Modeling of global plasma reaction on local cooling

→ Conclusions and outlook

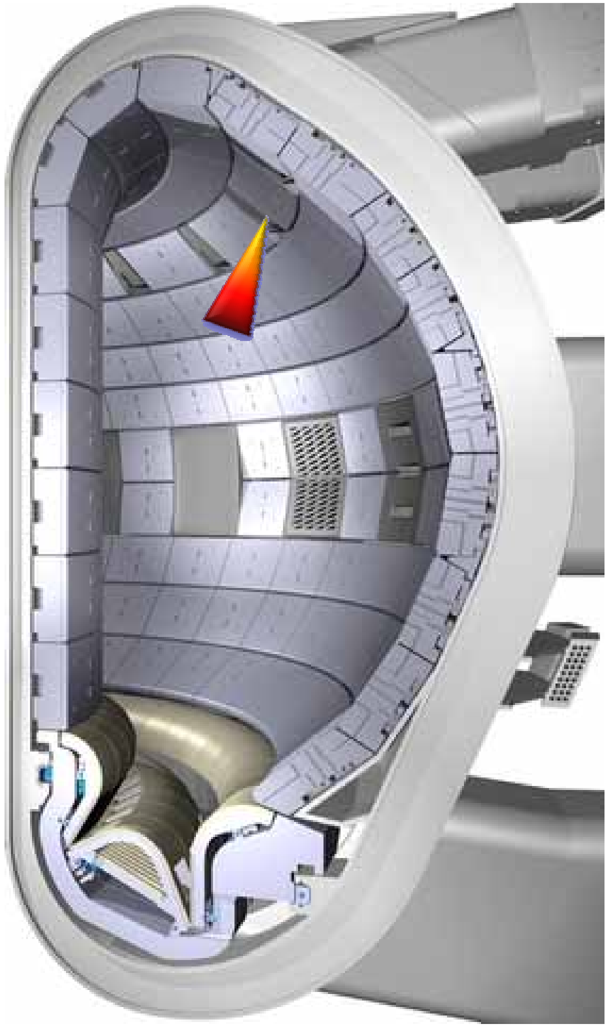
Impurity injection into tokamaks

→ Cooling down of plasma edge and weakening of plasma-wall interaction

→ Measurements of plasma parameters

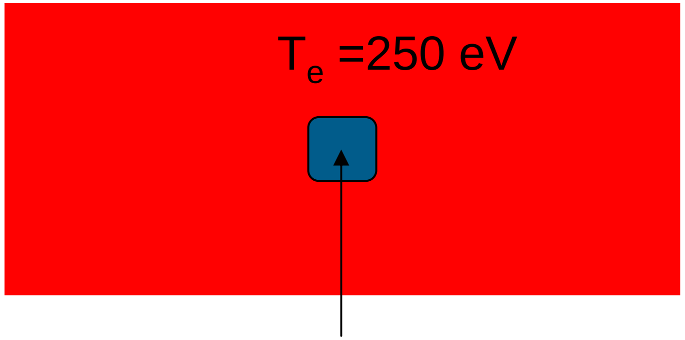
→ Investigation and modification of transport properties

→ Softening of harmful consequences of large MHD instabilities (disruption mitigation)



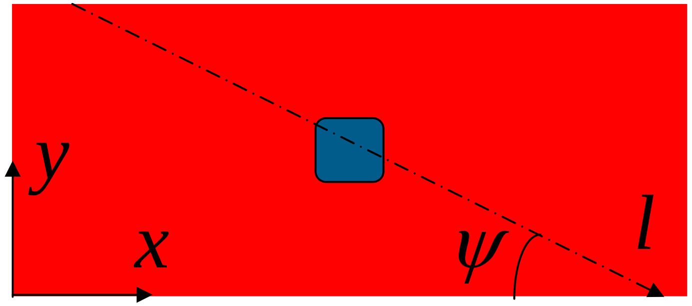
Plasma cooling mechanisms

- Cooling of electrons by inelastic collisions with impurity particles
- Cooling of ions by coulomb elastic collisions with impurity particles



Cloud of impurity neutrals and
singly charged ions $\rightarrow$
very fast T_e =1-2 eV

Global plasma reaction on local cooling



Through heat conduction $\kappa_{||}$ along magnetic field, direction l, whole magnetic surface is gradually cooled down:

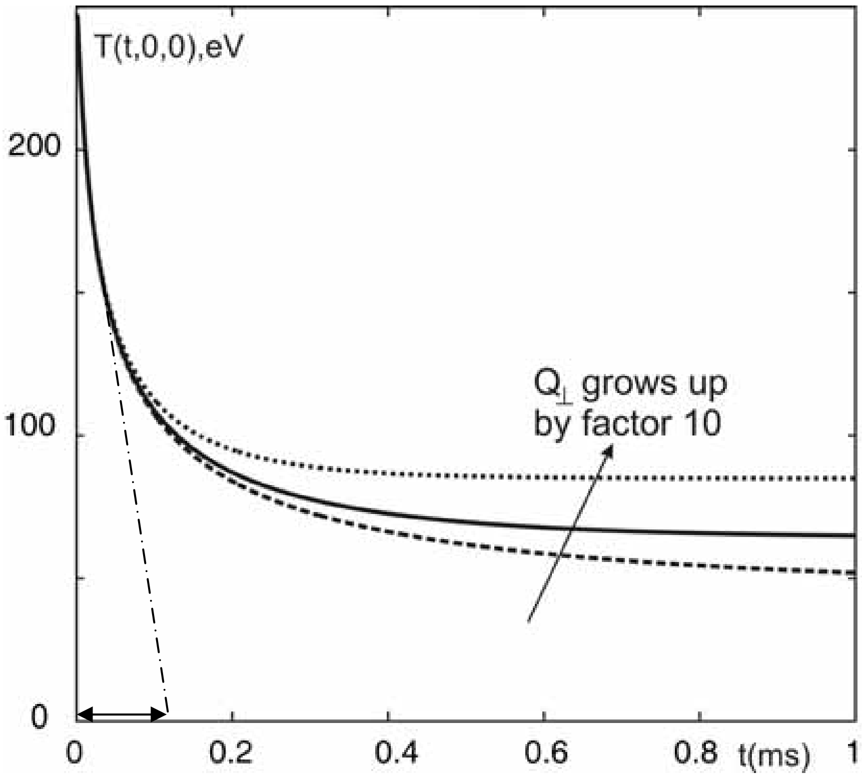
$$\partial_t\left(3nT\right)-\partial_l\left(\kappa_{||}\partial_l T\right)=Q_\perp\left(T_0-T\right)$$

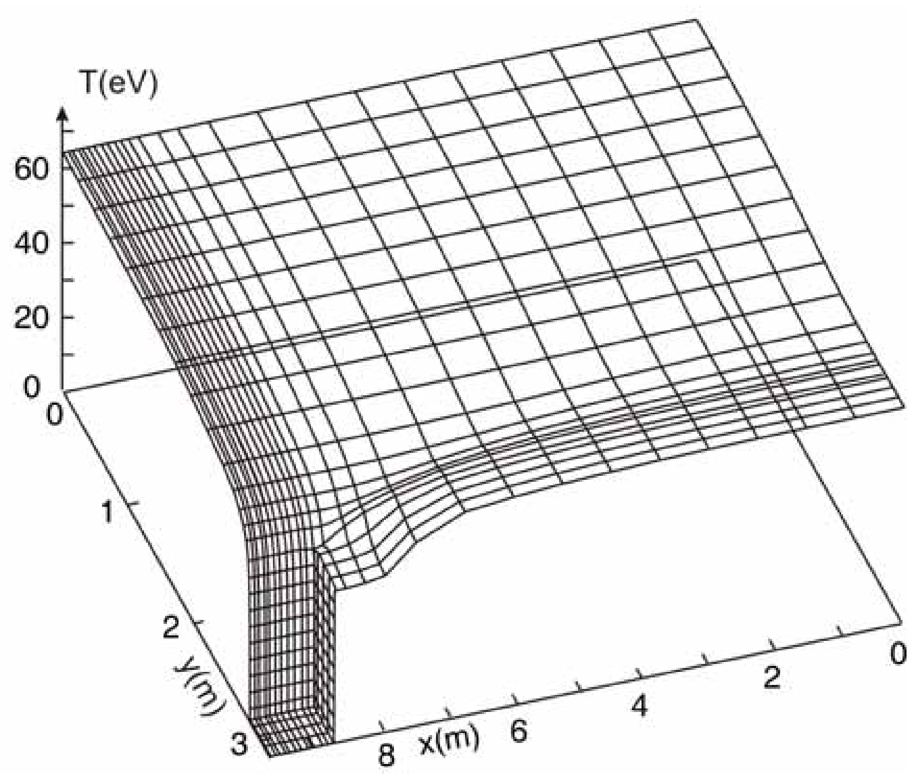
Problem: no boundary conditions in l-direction, but periodicity in toroidal x- and poloidal y-directions $\Rightarrow$ 2-D equation:

$$\partial_t\left(3nT\right)-\cos^2\psi\,\partial_x\left(\kappa_{||}\partial_x T\right)-\sin^2\psi\,\partial_y\left(\kappa_{||}\partial_y T\right)$$
$$-\sin\psi\cos\psi\left[\partial_x\left(\kappa_{||}\partial_y T\right)+\partial_y\left(\kappa_{||}\partial_x T\right)\right]=$$
$$=Q_\perp\left(T_0-T\right)$$

Calculations for JET MGI experiment I (T_0=250eV)

$$\kappa_{\parallel} = \kappa_{\parallel}^{SH}[m] \approx 10^{18} T^{2.5}[eV]$$



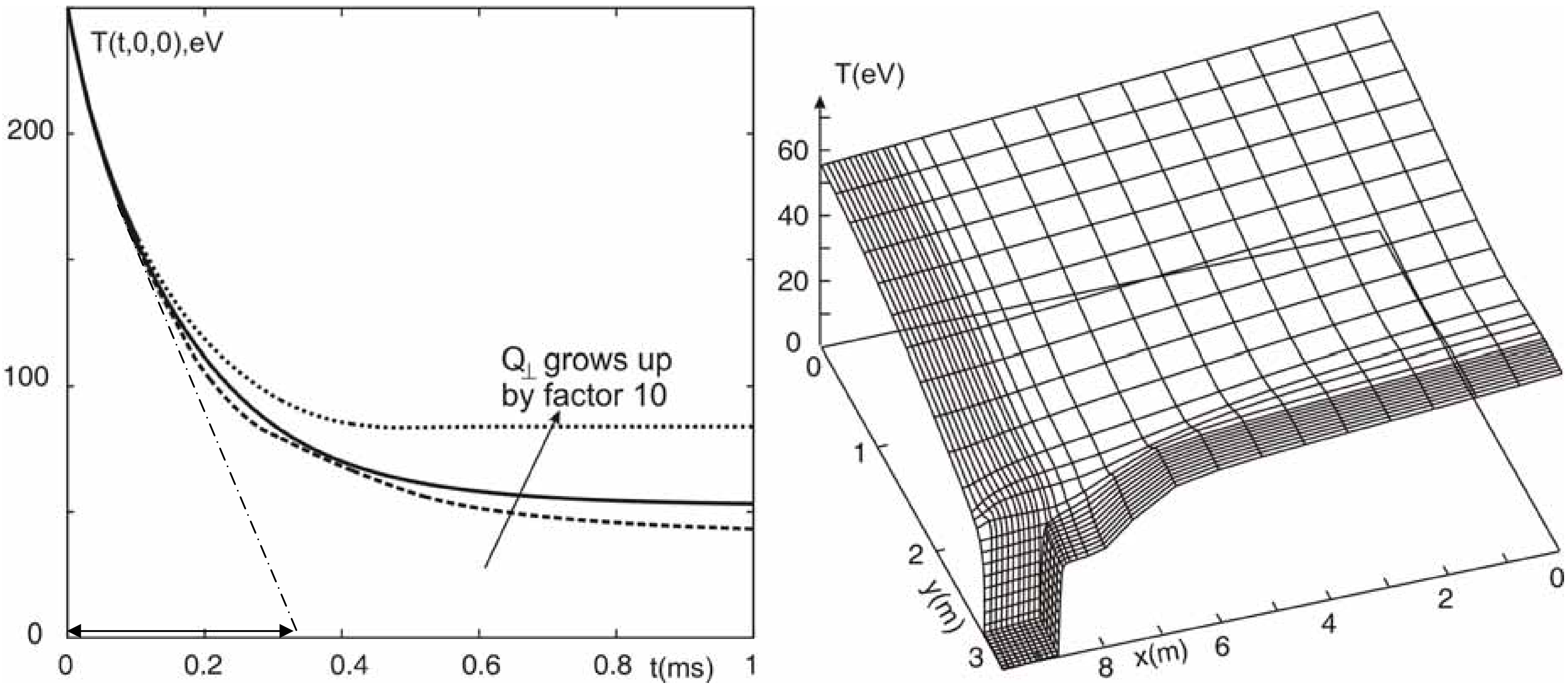


- Characteristic decay time of $T(t,0,0)$ changes weakly with $Q_{\perp}$
- This time is much smaller than in experiments, of 0.5 ms

Calculations for JET MGI experiment II (T_0=250eV)

Heat flux limit is taken into account
$\rightarrow$ heat conduction is dependent on temperature gradient:

$$\kappa_{\parallel} = \kappa_{\parallel}^{SH} \Big/ \left(1 + 100\lambda_c \left|\partial_l \ln T\right|\right)$$



- Significantly longer transient phase in better agreement with experiments
- Finite time of MGI has to be also taken into account

Conclusion & Outlook

- Impurity cools the plasma through different channels
- Compact structures with dense cold plasma develop if the impurity neutral density exceeds a critical one; ion-ion collisions are of most importance for the formation of such “bubbles”
- Heat flux limit is important to explain the transient time for cooling of regions far away from impurity injection position